FINAL TECHNICAL REPORT
September 2005

Equipment for Nonlinear Optics and Photonics Research
GRANT NO. W911NF-04-1-0366

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Summary:

This grant support from the Army Research Office (though 2004 DoD Instrumentation and Research Support Program for HBCU/MIs) has been used for acquisition of equipment to enhance nonlinear optics research and optics education programs at San Francisco State University (SFSU). The primary objective of the proposed project is to study optically-induced photonic lattices and discrete-solitons based on partially incoherent light, and to explore the possibility of using discrete solitons as information carriers for soliton-based switching, routing, and navigation. Another objective is to promote education and research of students at San Francisco State University, one of the national HBCU/MIs., in the fields of physical sciences and engineering.

As reported below, the work proposed in this project has been successfully completed, with more than 10 referred papers published during the project year which has credited ARO, and about a dozen students have participated in this project. Our work has been featured in *Optics & Photonic News*, *Physics Today* and *Technology Research News*.

Specifically, we have made the following progress as proposed in the original proposal:

1. Developed a mathematical model along with a computational method for studying light-induced photonic lattices. Demonstrated two-dimensional photonic lattices optically induced in bulk nonlinear materials with partially incoherent light.
2. Studied light propagation in light-induced photonic lattices. Demonstrated intrinsic localized modes of various configurations in weakly-coupled waveguide lattices, including two-dimensional discrete solitons, discrete stripe solitons, and discrete vortex solitons. Obtained solutions for such soliton states by use of a continuous model with periodic potentials as well as a discrete model.
3. Studied nonlinear interaction between and a soliton and a light-induced photonic lattice, and associated nonlinear phenomena including soliton-induced lattice dislocation, lattice deformation and compression, soliton dragging and routing, and signal propagation in discrete soliton network.
4. Explored potential applications of discrete solitons in all-optical devices and technology. Studied interactions and collisions between optical solitons embedded in photonic lattice structures for possible use in blocking, routing, and time-gating the transmission of intense laser signals.

Major Effort and Accomplishments:

During the project year supported by the ARO grant, the P.I. has made significant progress in the research work as proposed in the original proposal. About 10 papers have already been published in premier physic, mathematics and optics journals including *Physical Review Letters, Stud. Appl. Math,* and *Optics Letters.* More manuscripts have been accepted or submitted for review. (See attached list of publications that have acknowledged the support from ARO). Below are some examples of our successful research work.

1. Discrete-soliton trains in a light-induced photonic lattice

We have demonstrated anisotropic enhancement of discrete diffraction and formation of two-dimensional discrete-soliton trains in a light-induced photonic lattice. Such discrete-soliton trains were realized under appropriate conditions due to discrete modulation instability of a one-dimensional stripe beam in a two-dimensional lattice optically-induced with partially incoherent light. We have developed a mathematical mode and corroborated experimental results by numerical simulations. This work has been featured in cover page of Optics Express, March 2005 (see below).

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Editor-in-Chief: Michael Duncan Vol. 13, No. 6 - March 21, 2005 ISSN: 1094-4087

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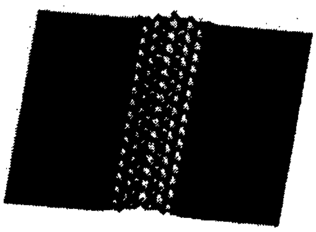

Discrete trapping of a stripe beam in a light-induced photonic lattice. The authors report on the formation of various types of discrete solitons in two-dimensional lattices. [See Chen *et al.*, Fig. 9 (b), for details.]

Focus Issue: Discrete solitons in nonlinear optics

2. High-order vortices and necklace structures in 2D photonic lattices

We have studied high-order vortices propagating in 2D photonic lattices using a continuous model with periodic lattice potentials as well as a discrete model. We have demonstrated the formation of stationary necklace-like solitons. Such ring soliton structures were realized when a high-order vortex beam was launched appropriately into a two-dimensional optically induced photonic lattice. Our theoretical results indicate that these necklace ring solitons are stable under certain conditions, in good agreement with experimental observations. This part of work has been included in two recent papers, one published in *Phys. Rev. E.*, and the other in *Physical Review Letters*. This work is also featured in *Technology Research News* 2005 (see below).

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Technology Research News

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System forms light necklace

The 1s and 0s of computer information are generally represented on computer chips by electrical signals. Using light signals instead promises to speed computing and more tightly integrate computers with optical communications lines.

Researchers from the University of Vermont, San Francisco State University, the University of Massachusetts at Amherst, Tel Aviv University in Israel, the University of Athens in Greece, and Nankai University in China who are working with soliton clusters have come a step closer to all-optical computing. A soliton is a sphere- or disk-shaped wave that does not spread out as it travels. The researchers have showed that it is possible to contain a lightwave as a soliton necklace -- a standing wave of light arranged as a ring of bright spots.

This type of lightwave control could eventually be used in micro-scale lightwave interference patterns, or photonic lattices, to carry out all-optical data processing, according to the researchers. In particular, the technique could be used to route light signals in all-optical communications devices and optoelectronic devices. The necklace soliton is also potentially useful as laser tweezers because it might have angular momentum that can be transferred to microparticles like cells.

To form a stable silicon necklace, the researchers shone a laser through a

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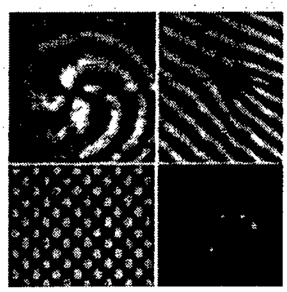
Stories:
Programmed DNA forms fractal
Dialogue system juggles topics
Scheme reverses light pulses
View from the High Ground: Joan Feigenbaum

Briefs:
Tough material gets functional
Water shifts rubber's shape
Interference scheme sharpens focus
System forms light necklace
Trapped light pulses interact
Optics demo does quantum logic
Strained material cleans up memory



Participation of underrepresented students in the proposed research

The P.I. has actively engaged students, especially underrepresented minorities, in his research. During the project year funded by ARO, a number of undergraduate and M.S. graduate students including woman and minority students have involved in the proposed research project.

Publications Acknowledged Support from ARO:
(Asterisk indicates SFSU student co-authors)

1. P.G. Kevrekidis, B. A. Malomed, Z. Chen, and D.J. Frantzeskakis, "Stable higher charge vortices in the discrete nonlinear Schrodinger equation", *Phys. Rev. E.* **70**, 056612 (2004).
2. J. Yang, A. Bezryadina*, I. Makasyuk, and Z. Chen, "Dipole and Quadripole solitons in optically-induced two-dimensional photonic lattices", *Stud. Appl. Math.* **113**, 389 (2004).
3. M. Asaro*, M. Sheldon*, J. Xu, Z. Chen, O. Ostroverkhova, W. E. Moerner, M. He and R. J. Twieg, "Soliton-induced waveguides in a photorefractive organic glass", accepted for publication in *Opt. Lett.* **30**, 519 (2005)
4. Z. Chen, H. Martin*, E. D. Eugenieva, J. Xu, J. Yang, and D. N. Christodoulides, "Formation of discrete solitons in light-induced photonic lattices", focus issue in *Opt. Express.* (invited by feature editor), **13**, 1816 (2005).
5. Z. Chen, H. Martin*, A. Bezryadina*, D.N. Neshev, Y.S. Kivshar, D. N. Christodoulides, "Experiments on Gaussian beams and vortices in optically-induced photonic lattices", special issue in *J. Opt. Soc. Am. B,* (invited by feature editor) **22**, 1305-1405 (2005).
6. J. Yang. I. Makasyuk, H. Martin, P.G. Kevrekidis, B.A. Malomed, D.J. Frantzeskakis, and Z. Chen, "Necklace-like solitons in optically induced photonic lattices", *Phys. Rev. Lett.* **94**, 113902 (2005).
7. Z. Chen, J. Xu, C. Lou, "Novel Discrete Solitons in Light-induced Photonic Lattices", *Physics (Wuli)*, **34**, 12 (2005). (invited review article, in Chinese).
8. P.G. Kevrekidis, Z. Chen, B.A. Malomed, D.J. Frantzeskakis, and M.I. Weinstein. "Spontaneous Symmetry Breaking in Photonic Lattices as a Bifurcation Problem: Theory, Numerics and Experiment". *Phys. Lett. A*, **340**, 275-280 (2005).
9. Francesco Fedele, Jianke Yang, Z. Chen, "Defect Modes in One-dimensional Photonic Lattices", *Opt. Lett.* **30**, 1506-1509 (2005).
10. T. Kapitula, P.G. Kevrekidis, Z. Chen, "Three is a crowd: Solitary waves in photorefractive media with three potential wells", *SIAM Journal in Applied Dynamical Systems*, to appear (2005).
11. C. Lou, J. Xu, L. Tang, Z. Chen, P.G. Kevrekidis, "Symmetric and anti-symmetric solitons and Bloch states in optically induced lattices", *Opt. Lett.* submitted (2005).
12. X. Wang, Z. Chen and P.G. Kevrekidis, "Discrete solitons and soliton rotation in periodic ring lattices", *Phys. Rev. Lett.* submitted (2005).

Equipment acquired:

INSTITUTION:	San Francisco State University
PROJECT DIRECTOR:	Zhigang Chen
TITLE:	Equipment for Nonlinear Optics and Photonics Research
SPONSOR:	2004 DoD Instrumentation and Research Support for HBCU/MIs

Equipment/Source	Cost
Solid State Laser Coherent Inc. Contact: Greg Losito (800) 400-3008	$ 55,000
Beamview profiler and data acquisition systems Coherent Auburn Group	$ 10,800
Optical Table and Air Compressor NewPort Corporation	$ 10,900
Photorefractive crystal and optics Altechna Co. Ltd	$ 7,500
Equipment Total	$ 84,200

This project has been successfully completed.
The support from DoD is highly appreciated!

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

DTIC Data

Purchase Request Number: FQ8671-0400388

BPN:

Proposal Number: 03-NM-100

Type Submission:

Inst. Control Number: F49620-03-1-0299P00002

Institution: SAN FRANCISCO STATE UNIVERSITY

Primary Investigator: Prfoessor Zhigang Chen

Invention Ind: none

Project/Task: 2304B / X

Program Manager: Dr. Arje Nachman

Objective:

This project seeks to derive more detailed understanding of the plasma processes within High Power Microwave tubes. Emphasis will be placed on determining the current limits on finite-size bunched pencil and annular electron beams and analyzing the stability of such bunched beams when relativistic conditions apply. These concerns will be taken up for various tube designs-klystrons, magnetrons, and MILOs. Finally the PI will look at the possible benefits of controlling mode competition within HPMs by inserting Photonic Band Gap material in suitable locations.

Approach:

The PI will employ Green's function techniques as well as theories from the fields of chaos and PBG.

Progress:

Year: 2004 **Month:** 10

ANNUAL REPORT FOR: F49620-03-1-01299

During the first project year supported by the AFOSR grant, the P.I. has made significant initial progress in the research work as proposed in the original proposal. Three manuscripts have already been published in Physical Review Letters and another 3 published in Optics Letters. More manuscripts have been accepted or submitted for review. (See attached list of publications that have acknowledged the support from AFOSR).

Year: 2004 **Month:**

ANNUAL REPORT FOR F49620-03-1-0299

During the last three months supported by the AFOSR grant, the P.1. has made significant initial progress in the research projects as proposed in the original proposal. Two manuscripts have already been finished and submitted to Physical Review Letters (see Reference below). Two more manuscripts are in preparation for submission. All these scientific papers acknowledged the support from AFOSR.

Light-induced 2D photonic lattices:

We developed a model, for the first time, for simulation of the formation of light-induced photonie lattices from partially incoherent light. This work suggests that stable robust waveguide lattices can be realized in linear and nonlinear regimes by use of photorefractive anisotropic nonlinearity and suppression of modulation instability of incoherent light waves. It is an important breakthrough in controlling light by light and in creation of two-dimensional photonic structures by optical induction rather than manual fabrication. Corresponding experimental results have been published in Optics Letters and in the special issue of Optics & Photonic News, "Optics in 2002". Here the problem with incoherent lattice formation was formulated and analyzed along with numerical simulations.

Progress:

Year: 2004 **Month:**

Soliton-induced lattice dislocation and 213 discrete solitons:

The P.1. propose to investigate the interaction between a light beam and a two-dimensional photonic lattice that is photo-induced in a photorefractive crystal using partially coherent light. Just as an electron interacting with a semiconductor, interaction between a soliton and a light-induced photonic lattice can lead to a host of new phenomena including lattice dislocation and creation of structures akin to optical polarons. Experimentally, we have demonstrated such interaction processes, along with the formation of two-dimensional discrete solitons in partially coherent photonie lattices. These experimental observations were corroborated by numerical simulations. The evolution of the partially coherent lattice is described by the so-called coherent density approach, and that of the coherent probe/soliton beam by a paraxial nonlinear wave equation, both solved numerically using a fast Fourier transform multi-beam propagation method. The figure below shows typical numerical results on discrete diffraction (left) and discrete solitons (right) established with a partially coherent photonic lattice. This part of the work has been submitted to Physical Review Letters [1].

Year: 2005 **Month:** 11

Annual Report For F49620-03-1-0299

The primary objective of this project is to study optically-induced photonic lattices and discrete-solitons based on partially incoherent light, and to explore the possibility of using discrete solitons as information carriers for soliton-based switching, routing, and navigation. Another objective is to promote education and research of students at San Francisco State University, one of the national HBCU/MIs., in the fields of physical sciences and engineering. These objectives are fully in line with the goal of AFOSR grant support. As detailed in this report, the work proposed in the project has been completed, with about 20 referred papers published in the last 3 years that credited AFOSR, and about a dozen students participated in this project supported by AFOSR. Our work has been featured in Optics & Photonic News, Physics Today and Technology Research News. Part of the progress made in this project has been reported in our previous aimual reports, and has also been presented at the Workshop on Nonlinear Optics in Tucson, Arizona, sponsored by AFOSR.

Year: 2006 **Month:** 01 **Final**

Final Report for F49620-03-1-0299

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As reported below, the work proposed in this project has been successfully completed, with more than 10 referred papers published during the project year which has credited ARO, and about a dozen students have participated in this project. Our work has been featured in Optics & Photonic News, Physics Today and Technology Research News.

REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-06-0007

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		Final

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AFOSR- Dr. Nachman

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12a. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

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	16. PRICE CODE

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